DISSIPATION IN TETRAHEDRAL AMORPHOUS CARBON OSCILLATORS

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Abstract

Tetrahedral amorphous carbon (ta-C) films have been used to fabricate micro-electromechanical systems (MEMS) with broad applications such as electronics (as clocks, filters, switches, etc.), sensors (for chemicals, biological agents, pressure, acceleration, etc.), and metrology (scanning probe microscopy). These films have superior properties to other common MEMS films such as silicon, polysilicon, silicon nitride and silicon dioxide. The Youngs' Modulus of ta-C (approximately 80% sp^3 bonding) is roughly 4 times that of the other common films, which can aide in the realization of high frequency oscillators for filter and other applications. Additionally, the ta-C films are resistant to stiction and auto-adhesion and have an abrupt surface termination, which helps prevent surface losses. Understanding surface losses and other dissipation mechanisms that limit quality factor, Q, in ta-C is essential for realization of components for electronic or sensor applications since the bandwidth for electronic components scales as Q^{-1} and the sensitivity of sensors scales as $Q^{-½}$.

We have fabricated three different oscillator structures out of ta-C: out-of-plane cantilevers, in-plane cantilevers, and free-free beam oscillators with frequencies ranging from about 1 kHz to 5 MHz. At room temperature, these structures show a consistent quality factor of approximately 3 x 10^3 over the entire frequency range, similar to that observed for other amorphous materials such as silicon dioxide. We have compared the dissipation in these oscillators with the calculated dissipation due to thermoelastic dissipation, dissipation due to phonon-mechanical vibration interaction, mechanical clamping losses, and dissipation due to defects in the material. The observed constant quality factor is only consistent with a spectrum of defects with roughly the same concentration (Fig. 1). At room temperature, the activation energies for this spectrum of defects range from 0.35 to 0.55 eV, but the atomic nature of the defect relaxation processes is not understood. In order to study a broader range of activation energies and gain insight on defect relaxation mechanisms, we performed temperature-dependent measurements on out-of-plane cantilevers having different resonant frequencies over the temperature range from 30ºC to 500ºC. From Fig 2, it can be seen that at approximately 0.8 eV the relative concentration of defects increases. These energies are approaching the activation energies for diffusional defect relaxation processes in crystalline diamond films, such as self-interstitial diffusion (1.3 eV) and vacancy self-diffusion (2.3 eV). Understanding the temperature dependence of the internal dissipation in this material is important to ensure functionality of ta-C resonators at elevated temperatures when used in filter or sensor applications.

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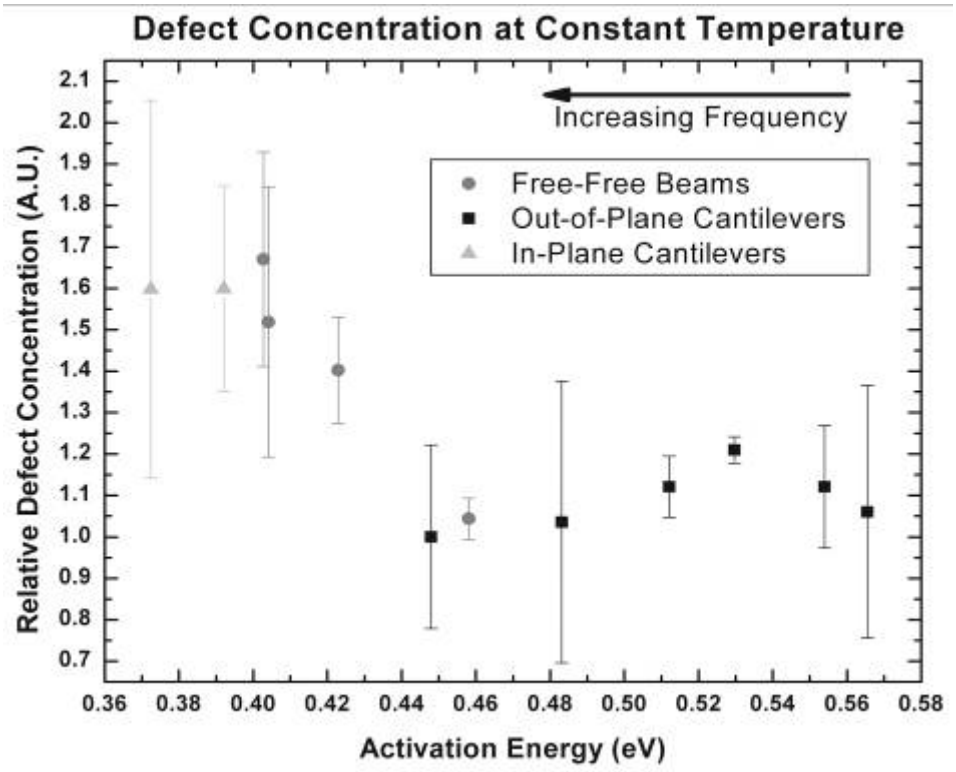

Figure 1

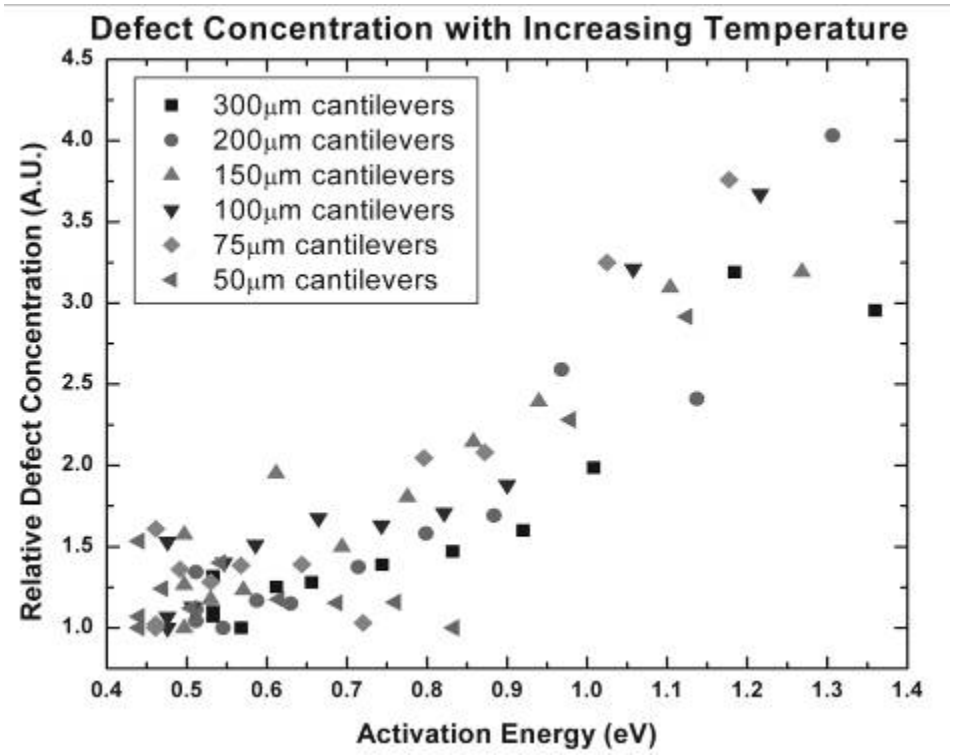

Figure 2